[*The potential due to an **electric dipole** drops off as $1/r^2$. The **dipole moment** is $p = Q\ell$, where ℓ is the distance between the two equal but opposite charges of magnitude Q.]

A **capacitor** is a device used to store charge (and electric energy), and consists of two nontouching conductors. The two conductors hold equal and opposite charges, of magnitude Q. The ratio of this charge Q to the potential difference V between the conductors is called the **capacitance**, C:

$$C = \frac{Q}{V}, \quad \text{or} \quad Q = CV. \qquad (17\text{–}7)$$

The capacitance of a parallel-plate capacitor is proportional to the area A of each plate and inversely proportional to their separation d:

$$C = \epsilon_0 \frac{A}{d}. \qquad (17\text{–}8)$$

The space between the two conductors of a capacitor contains a nonconducting material such as air, paper, or plastic. These materials are referred to as **dielectrics**, and the capacitance is proportional to a property of dielectrics called the **dielectric constant**, K (equal to 1 for air).

A charged capacitor stores an amount of electric energy given by

$$\text{PE} = \tfrac{1}{2}QV = \tfrac{1}{2}CV^2 = \tfrac{1}{2}\frac{Q^2}{C}. \qquad (17\text{–}10)$$

This energy can be thought of as stored in the electric field between the plates.

The energy stored in any electric field E has a density

$$\frac{\text{electric PE}}{\text{volume}} = \tfrac{1}{2}\epsilon_0 E^2. \qquad (17\text{–}11)$$

Digital electronics converts an analog **signal voltage** into an approximate digital voltage based on a **binary code**: each **bit** has two possibilities, 1 or 0 (also "on" or "off"). The binary number 1101 equals 13. A **byte** is 8 bits and provides $2^8 = 256$ voltage levels. **Sampling rate** is the number of voltage measurements done on the analog signal per second. The **bit depth** is the number of digital voltage levels available at each sampling. CDs are 44.1 kHz, 16-bit.

[*TV and computer monitors traditionally used a **cathode ray tube** (CRT) which accelerates electrons by high voltage, and sweeps them across the screen in a regular way using magnetic coils or electric deflection plates. **LCD flat screens** contain millions of **pixels**, each with a red, green, and blue **subpixel** whose brightness is addressed every $\frac{1}{60}$ s via a **matrix** of horizontal and vertical wires using a **digital (binary)** code.]

[*An **electrocardiogram** (ECG or EKG) records the potential changes of each heart beat as the cells depolarize and repolarize.]

Chapter - 17

Questions

1. If two points are at the same potential, does this mean that no net work is done in moving a test charge from one point to the other? Does this imply that no force must be exerted? Explain.
2. If a negative charge is initially at rest in an electric field, will it move toward a region of higher potential or lower potential? What about a positive charge? How does the potential energy of the charge change in each instance? Explain.
3. State clearly the difference (*a*) between electric potential and electric field, (*b*) between electric potential and electric potential energy.
4. An electron is accelerated from rest by a potential difference of 0.20 V. How much greater would its final speed be if it is accelerated with four times as much voltage? Explain.
5. Is there a point along the line joining two equal positive charges where the electric field is zero? Where the electric potential is zero? Explain.
6. Can a particle ever move from a region of low electric potential to one of high potential and yet have its electric potential energy decrease? Explain.
7. If $V = 0$ at a point in space, must $\vec{\mathbf{E}} = 0$? If $\vec{\mathbf{E}} = 0$ at some point, must $V = 0$ at that point? Explain. Give examples for each.
8. Can two equipotential lines cross? Explain.
9. Draw in a few equipotential lines in Fig. 16–32b and c.
10. When a battery is connected to a capacitor, why do the two plates acquire charges of the same magnitude? Will this be true if the two plates are different sizes or shapes?
11. A conducting sphere carries a charge Q and a second identical conducting sphere is neutral. The two are initially isolated, but then they are placed in contact. (*a*) What can you say about the potential of each when they are in contact? (*b*) Will charge flow from one to the other? If so, how much?
12. The parallel plates of an isolated capacitor carry opposite charges, Q. If the separation of the plates is increased, is a force required to do so? Is the potential difference changed? What happens to the work done in the pulling process?
13. If the electric field $\vec{\mathbf{E}}$ is uniform in a region, what can you infer about the electric potential V? If V is uniform in a region of space, what can you infer about $\vec{\mathbf{E}}$?
14. Is the electric potential energy of two isolated unlike charges positive or negative? What about two like charges? What is the significance of the sign of the potential energy in each case?
15. If the voltage across a fixed capacitor is doubled, the amount of energy it stores (*a*) doubles; (*b*) is halved; (*c*) is quadrupled; (*d*) is unaffected; (*e*) none of these. Explain.
16. How does the energy stored in a capacitor change when a dielectric is inserted if (*a*) the capacitor is isolated so Q does not change; (*b*) the capacitor remains connected to a battery so V does not change? Explain.
17. A dielectric is pulled out from between the plates of a capacitor which remains connected to a battery. What changes occur to (*a*) the capacitance, (*b*) the charge on the plates, (*c*) the potential difference, (*d*) the energy stored in the capacitor, and (*e*) the electric field? Explain your answers.
18. We have seen that the capacitance C depends on the size and position of the two conductors, as well as on the dielectric constant K. What then did we mean when we said that C is a constant in Eq. 17–7?

MisConceptual Questions

1. A $+0.2\,\mu C$ charge is in an electric field. What happens if that charge is replaced by a $+0.4\,\mu C$ charge?
   (*a*) The electric potential doubles, but the electric potential energy stays the same.
   (*b*) The electric potential stays the same, but the electric potential energy doubles.
   (*c*) Both the electric potential and electric potential energy double.
   (*d*) Both the electric potential and electric potential energy stay the same.

2. Two identical positive charges are placed near each other. At the point halfway between the two charges,
   (*a*) the electric field is zero and the potential is positive.
   (*b*) the electric field is zero and the potential is zero.
   (*c*) the electric field is not zero and the potential is positive.
   (*d*) the electric field is not zero and the potential is zero.
   (*e*) None of these statements is true.

3. Four identical point charges are arranged at the corners of a square [*Hint*: Draw a figure]. The electric field E and potential V at the center of the square are
   (*a*) $E = 0,\ V = 0$.
   (*b*) $E = 0,\ V \neq 0$.
   (*c*) $E \neq 0,\ V \neq 0$.
   (*d*) $E \neq 0,\ V = 0$.
   (*e*) $E = V$ regardless of the value.

4. Which of the following statements is valid?
   (*a*) If the potential at a particular point is zero, the field at that point must be zero.
   (*b*) If the field at a particular point is zero, the potential at that point must be zero.
   (*c*) If the field throughout a particular region is constant, the potential throughout that region must be zero.
   (*d*) If the potential throughout a particular region is constant, the field throughout that region must be zero.

5. If it takes an amount of work W to move two $+q$ point charges from infinity to a distance d apart from each other, then how much work should it take to move three $+q$ point charges from infinity to a distance d apart from each other?
   (*a*) $2W$.
   (*b*) $3W$.
   (*c*) $4W$.
   (*d*) $6W$.

6. A proton ($Q = +e$) and an electron ($Q = -e$) are in a constant electric field created by oppositely charged plates. You release the proton from near the positive plate and the electron from near the negative plate. Which feels the larger electric force?
   (*a*) The proton.
   (*b*) The electron.
   (*c*) Neither—there is no force.
   (*d*) The magnitude of the force is the same for both and in the same direction.
   (*e*) The magnitude of the force is the same for both but in opposite directions.

7. When the proton and electron in MisConceptual Question 6 strike the opposite plate, which one has more kinetic energy?
   (*a*) The proton.
   (*b*) The electron.
   (*c*) Both acquire the same kinetic energy.
   (*d*) Neither—there is no change in kinetic energy.
   (*e*) They both acquire the same kinetic energy but with opposite signs.

8. Which of the following do not affect capacitance?
   (*a*) Area of the plates.
   (*b*) Separation of the plates.
   (*c*) Material between the plates.
   (*d*) Charge on the plates.
   (*e*) Energy stored in the capacitor.

9. A battery establishes a voltage V on a parallel-plate capacitor. After the battery is disconnected, the distance between the plates is doubled without loss of charge. Accordingly, the capacitance ________ and the voltage between the plates ________.
   (*a*) increases; decreases.
   (*b*) decreases; increases.
   (*c*) increases; increases.
   (*d*) decreases; decreases.
   (*e*) stays the same; stays the same.

10. Which of the following is a vector?
    (*a*) Electric potential.
    (*b*) Electric potential energy.
    (*c*) Electric field.
    (*d*) Equipotential lines.
    (*e*) Capacitance.

11. A $+0.2\,\mu C$ charge is in an electric field. What happens if that charge is replaced by a $-0.2\,\mu C$ charge?
    (*a*) The electric potential changes sign, but the electric potential energy stays the same.
    (*b*) The electric potential stays the same, but the electric potential energy changes sign.
    (*c*) Both the electric potential and electric potential energy change sign.
    (*d*) Both the electric potential and electric potential energy stay the same.

For assigned homework and other learning materials, go to the MasteringPhysics website.

Problems

17–1 to 17–4 Electric Potential

1. (I) How much work does the electric field do in moving a $-7.7\,\mu C$ charge from ground to a point whose potential is $+65$ V higher?

2. (I) How much work does the electric field do in moving a proton from a point at a potential of $+125$ V to a point at -45 V? Express your answer both in joules and electron volts.

3. (I) What potential difference is needed to stop an electron that has an initial velocity $v = 6.0 \times 10^5$ m/s?

4. (I) How much kinetic energy will an electron gain (in joules and eV) if it accelerates through a potential difference of 18,500 V?

5. (I) An electron acquires 6.45×10^{-16} J of kinetic energy when it is accelerated by an electric field from plate A to plate B. What is the potential difference between the plates, and which plate is at the higher potential?

6. (I) How strong is the electric field between two parallel plates 6.8 mm apart if the potential difference between them is 220 V?

7. (I) An electric field of 525 V/m is desired between two parallel plates 11.0 mm apart. How large a voltage should be applied?

8. (I) The electric field between two parallel plates connected to a 45-V battery is 1900 V/m. How far apart are the plates?

9. (I) What potential difference is needed to give a helium nucleus ($Q = 2e$) 85.0 keV of kinetic energy?

10. (II) Two parallel plates, connected to a 45-V power supply, are separated by an air gap. How small can the gap be if the air is not to become conducting by exceeding its breakdown value of $E = 3 \times 10^6$ V/m?

11. (II) The work done by an external force to move a $-6.50\,\mu C$ charge from point A to point B is 15.0×10^{-4} J. If the charge was started from rest and had 4.82×10^{-4} J of kinetic energy when it reached point B, what must be the potential difference between A and B?

12. (II) What is the speed of an electron with kinetic energy (*a*) 850 eV, and (*b*) 0.50 keV?

13. (II) What is the speed of a proton whose KE is 4.2 keV?

14. (II) An alpha particle (which is a helium nucleus, $Q = +2e$, $m = 6.64 \times 10^{-27}$ kg) is emitted in a radioactive decay with KE = 5.53 MeV. What is its speed?

15. (II) An electric field greater than about 3×10^6 V/m causes air to break down (electrons are removed from the atoms and then recombine, emitting light). See Section 17–2 and Table 17–3. If you shuffle along a carpet and then reach for a doorknob, a spark flies across a gap you estimate to be 1 mm between your finger and the doorknob. Estimate the voltage between your finger and the doorknob. Why is no harm done?

16. (II) An electron starting from rest acquires 4.8 keV of KE in moving from point A to point B. (*a*) How much KE would a proton acquire, starting from rest at B and moving to point A? (*b*) Determine the ratio of their speeds at the end of their respective trajectories.

17. (II) Draw a conductor in the oblong shape of a football. This conductor carries a net negative charge, $-Q$. Draw in a dozen or so electric field lines and equipotential lines.

17–5 Potential Due to Point Charges

[Let $V = 0$ at $x = \infty$.]

18. (I) What is the electric potential 15.0 cm from a 3.00 μC point charge?

19. (I) A point charge Q creates an electric potential of $+165$ V at a distance of 15 cm. What is Q?

20. (II) A $+35\,\mu C$ point charge is placed 46 cm from an identical $+35\,\mu C$ charge. How much work would be required to move a $+0.50\,\mu C$ test charge from a point midway between them to a point 12 cm closer to either of the charges?

21. (II) (*a*) What is the electric potential 2.5×10^{-15} m away from a proton (charge $+e$)? (*b*) What is the electric potential energy of a system that consists of two protons 2.5×10^{-15} m apart—as might occur inside a typical nucleus?

22. (II) Three point charges are arranged at the corners of a square of side ℓ as shown in Fig. 17–39. What is the potential at the fourth corner (point A)?

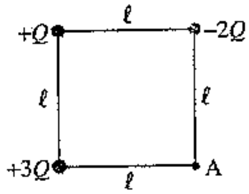

FIGURE 17–39 Problem 22.

23. (II) An electron starts from rest 24.5 cm from a fixed point charge with $Q = -6.50$ nC. How fast will the electron be moving when it is very far away?

24. (II) Two identical $+9.5\,\mu C$ point charges are initially 5.3 cm from each other. If they are released at the same instant from rest, how fast will each be moving when they are very far away from each other? Assume they have identical masses of 1.0 mg.

25. (II) Two point charges, $3.0\,\mu C$ and $-2.0\,\mu C$, are placed 4.0 cm apart on the x axis. At what points along the x axis is (*a*) the electric field zero and (*b*) the potential zero?

26. (II) How much work must be done to bring three electrons from a great distance apart to 1.0×10^{-10} m from one another (at the corners of an equilateral triangle)?

27. (II) Point a is 62 cm north of a $-3.8\,\mu C$ point charge, and point b is 88 cm west of the charge (Fig. 17–40). Determine (*a*) $V_b - V_a$ and (*b*) $\vec{E}_b - \vec{E}_a$ (magnitude and direction).

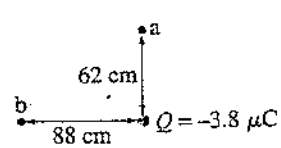

FIGURE 17–40 Problem 27.

28. (II) Many chemical reactions release energy. Suppose that at the beginning of a reaction, an electron and proton are separated by 0.110 nm, and their final separation is 0.100 nm. How much electric potential energy was lost in this reaction (in units of eV)?

29. (III) How much voltage must be used to accelerate a proton (radius 1.2×10^{-15} m) so that it has sufficient energy to just "touch" a silicon nucleus? A silicon nucleus has a charge of $+14e$, and its radius is about 3.6×10^{-15} m. Assume the potential is that for point charges.

30. (III) Two equal but opposite charges are separated by a distance d, as shown in Fig. 17–41. Determine a formula for $V_{BA} = V_B - V_A$ for points B and A on the line between the charges situated as shown.

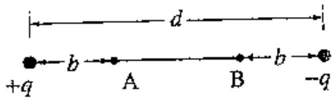

FIGURE 17–41 Problem 30.

31. (III) In the Bohr model of the hydrogen atom, an electron orbits a proton (the nucleus) in a circular orbit of radius 0.53×10^{-10} m. (a) What is the electric potential at the electron's orbit due to the proton? (b) What is the kinetic energy of the electron? (c) What is the total energy of the electron in its orbit? (d) What is the *ionization energy*—that is, the energy required to remove the electron from the atom and take it to $r = \infty$, at rest? Express the results of parts (b), (c), and (d) in joules and eV.

*17–6 Electric Dipoles

*32. (I) An electron and a proton are 0.53×10^{-10} m apart. What is their dipole moment if they are at rest?

*33. (II) Calculate the electric potential due to a dipole whose dipole moment is 4.2×10^{-30} C·m at a point 2.4×10^{-9} m away if this point is (a) along the axis of the dipole nearer the positive charge; (b) 45° above the axis but nearer the positive charge; (c) 45° above the axis but nearer the negative charge.

*34. (III) The dipole moment, considered as a vector, points from the negative to the positive charge. The water molecule, Fig. 17–42, has a dipole moment $\vec{p}$ which can be considered as the vector sum of the two dipole moments, $\vec{p}_1$ and $\vec{p}_2$, as shown. The distance between each H and the O is about 0.96×10^{-10} m. The lines joining the center of the O atom with each H atom make an angle of 104°, as shown, and the net dipole moment has been measured to be $p = 6.1 \times 10^{-30}$ C·m. Determine the charge q on each H atom.

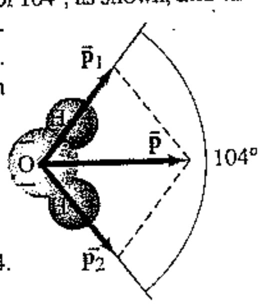

FIGURE 17–42 Problem 34. A water molecule, H_2O.

17–7 Capacitance

35. (I) The two plates of a capacitor hold $+2500\,\mu$C and $-2500\,\mu$C of charge, respectively, when the potential difference is 960 V. What is the capacitance?

36. (I) An 8500-pF capacitor holds plus and minus charges of 16.5×10^{-8} C. What is the voltage across the capacitor?

37. (I) How much charge flows from each terminal of a 12.0-V battery when it is connected to a 5.00-μF capacitor?

38. (I) A 0.20-F capacitor is desired. What area must the plates have if they are to be separated by a 3.2-mm air gap?

39. (II) The charge on a capacitor increases by 15 μC when the voltage across it increases from 97 V to 121 V. What is the capacitance of the capacitor?

40. (II) An electric field of 8.50×10^5 V/m is desired between two parallel plates, each of area 45.0 cm^2 and separated by 2.45 mm of air. What charge must be on each plate?

41. (II) If a capacitor has opposite 4.2 μC charges on the plates, and an electric field of 2.0 kV/mm is desired between the plates, what must each plate's area be?

42. (II) It takes 18 J of energy to move a 0.30-mC charge from one plate of a 15-μF capacitor to the other. How much charge is on each plate?

43. (II) To get an idea how big a farad is, suppose you want to make a 1-F air-filled parallel-plate capacitor for a circuit you are building. To make it a reasonable size, suppose you limit the plate area to 1.0 cm^2. What would the gap have to be between the plates? Is this practically achievable?

44. (II) How strong is the electric field between the plates of a 0.80-μF air-gap capacitor if they are 2.0 mm apart and each has a charge of 62 μC?

45. (III) A 2.50-μF capacitor is charged to 746 V and a 6.80-μF capacitor is charged to 562 V. These capacitors are then disconnected from their batteries. Next the positive plates are connected to each other and the negative plates are connected to each other. What will be the potential difference across each and the charge on each? [*Hint:* Charge is conserved.]

46. (III) A 7.7-μF capacitor is charged by a 165-V battery (Fig. 17–43a) and then is disconnected from the battery. When this capacitor (C_1) is then connected (Fig. 17–43b) to a second (initially uncharged) capacitor, C_2, the final voltage on each capacitor is 15 V. What is the value of C_2? [*Hint:* Charge is conserved.]

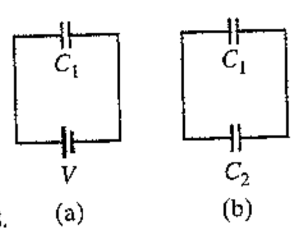

FIGURE 17–43 Problems 46 and 58.

17–8 Dielectrics

47. (I) What is the capacitance of two square parallel plates 6.6 cm on a side that are separated by 1.8 mm of paraffin?

48. (I) What is the capacitance of a pair of circular plates with a radius of 5.0 cm separated by 2.8 mm of mica?

49. (II) An uncharged capacitor is connected to a 21.0-V battery until it is fully charged, after which it is disconnected from the battery. A slab of paraffin is then inserted between the plates. What will now be the voltage between the plates?

50. (II) A 3500-pF air-gap capacitor is connected to a 32-V battery. If a piece of mica is placed between the plates, how much charge will flow from the battery?

51. (II) The electric field between the plates of a paper-separated ($K = 3.75$) capacitor is 8.24×10^4 V/m. The plates are 1.95 mm apart, and the charge on each is 0.675 μC. Determine the capacitance of this capacitor and the area of each plate.

17–9 Electric Energy Storage

52. (I) 650 V is applied to a 2800-pF capacitor. How much energy is stored?

53. (I) A cardiac defibrillator is used to shock a heart that is beating erratically. A capacitor in this device is charged to 5.0 kV and stores 1200 J of energy. What is its capacitance?

54. (II) How much energy is stored by the electric field between two square plates, 8.0 cm on a side, separated by a 1.5-mm air gap? The charges on the plates are equal and opposite and of magnitude 370 μC.

55. (II) A homemade capacitor is assembled by placing two 9-in. pie pans 4 cm apart and connecting them to the opposite terminals of a 9-V battery. Estimate (*a*) the capacitance, (*b*) the charge on each plate, (*c*) the electric field halfway between the plates, and (*d*) the work done by the battery to charge them. (*e*) Which of the above values change if a dielectric is inserted?

56. (II) A parallel-plate capacitor has fixed charges $+Q$ and $-Q$. The separation of the plates is then halved. (*a*) By what factor does the energy stored in the electric field change? (*b*) How much work must be done to reduce the plate separation from d to $\frac{1}{2}d$? The area of each plate is A.

57. (II) There is an electric field near the Earth's surface whose magnitude is about 150 V/m. How much energy is stored per cubic meter in this field?

58. (III) A 3.70-μF capacitor is charged by a 12.0-V battery. It is disconnected from the battery and then connected to an uncharged 5.00-μF capacitor (Fig. 17–43). Determine the total stored energy (*a*) before the two capacitors are connected, and (*b*) after they are connected. (*c*) What is the change in energy?

17–10 Digital

59. (I) Write the decimal number 116 in binary.

60. (I) Write the binary number 01010101 as a decimal number.

61. (I) Write the binary number 1010101010101010 as a decimal number.

62. (II) Consider a rather coarse 4-bit analog-to-digital conversion where the maximum voltage is 5.0 V. (*a*) What voltage does 1011 represent? (*b*) What is the 4-bit representation for 2.0 V?

63. (II) (*a*) 16-bit sampling provides how many different possible voltages? (*b*) 24-bit sampling provides how many different possible voltages? (*c*) For color TV, 3 subpixels, each 8 bits, provides a total of how many different colors?

64. (II) A few extraterrestrials arrived. They had two hands, but claimed that 3 + 2 = 11. How many fingers did they have on their two hands? Note that our decimal system (and ten characters: 0, 1, 2, ···, 9) surely has its origin because we have ten fingers. [*Hint*: 11 is in their system. In our decimal system, the result would be written as 5.]

*17–11 TV and Computer Monitors

*65. (II) Figure 17–44 is a photograph of a computer screen shot by a camera set at an exposure time of $\frac{1}{4}$ s. During the exposure the cursor arrow was moved around by the mouse, and we see it 15 times. (*a*) Explain why we see the cursor 15 times. (*b*) What is the refresh rate of the screen?

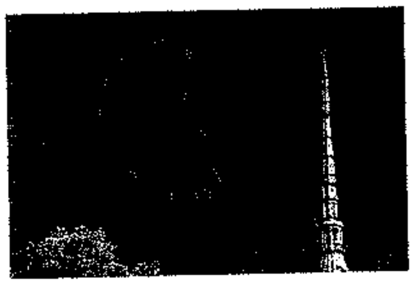

FIGURE 17–44 Problem 65.

*66. (III) In a given CRT, electrons are accelerated horizontally by 9.0 kV. They then pass through a uniform electric field E for a distance of 2.8 cm, which deflects them upward so they travel 22 cm to the top of the screen, 11 cm above the center. Estimate the value of E.

*67. (III) Electrons are accelerated by 6.0 kV in a CRT. The screen is 30 cm wide and is 34 cm from the 2.6-cm-long deflection plates. Over what range must the horizontally deflecting electric field vary to sweep the beam fully across the screen?

General Problems

68. A lightning flash transfers 4.0 C of charge and 5.2 MJ of energy to the Earth. (*a*) Across what potential difference did it travel? (*b*) How much water could this boil and vaporize, starting from room temperature? (See also Chapter 14.)

69. In an older television tube, electrons are accelerated by thousands of volts through a vacuum. If a television set were laid on its back, would electrons be able to move upward against the force of gravity? What potential difference, acting over a distance of 2.4 cm, would be needed to balance the downward force of gravity so that an electron would remain stationary? Assume that the electric field is uniform.

70. How does the energy stored in a capacitor change, as the capacitor remains connected to a battery, if the separation of the plates is doubled?

71. How does the energy stored in an isolated capacitor change if (*a*) the potential difference is doubled, or (*b*) the separation of the plates is doubled?

72. A huge 4.0-F capacitor has enough stored energy to heat 2.8 kg of water from 21°C to 95°C. What is the potential difference across the plates?

73. A proton ($q = +e$) and an alpha particle ($q = +2e$) are accelerated by the same voltage V. Which gains the greater kinetic energy, and by what factor?

74. Dry air will break down if the electric field exceeds 3.0×10^6 V/m. What amount of charge can be placed on a parallel-plate capacitor if the area of each plate is 65 cm^2?

75. Three charges are at the corners of an equilateral triangle (side ℓ) as shown in Fig. 17–45. Determine the potential at the midpoint of each of the sides. Let $V = 0$ at $r = \infty$.

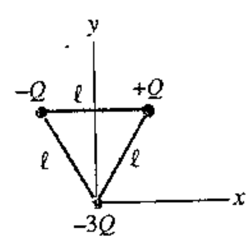

FIGURE 17–45 Problem 75.

76. It takes 15.2 J of energy to move a 13.0-mC charge from one plate of a 17.0-μF capacitor to the other. How much charge is on each plate? Assume constant voltage.

77. A 3.4 μC and a $-2.6\,\mu$C charge are placed 2.5 cm apart. At what points along the line joining them is (*a*) the electric field zero, and (*b*) the electric potential zero?

78. Near the surface of the Earth there is an electric field of about 150 V/m which points downward. Two identical balls with mass $m = 0.670$ kg are dropped from a height of 2.00 m, but one of the balls is positively charged with $q_1 = 650\,\mu$C, and the second is negatively charged with $q_2 = -650\,\mu$C. Use conservation of energy to determine the difference in the speed of the two balls when they hit the ground. (Neglect air resistance.)

79. The power supply for a pulsed nitrogen laser has a 0.050-μF capacitor with a maximum voltage rating of 35 kV. (*a*) Estimate how much energy could be stored in this capacitor. (*b*) If 12% of this stored electrical energy is converted to light energy in a pulse that is 6.2 microseconds long, what is the power of the laser pulse?

80. In a **photocell**, ultraviolet (UV) light provides enough energy to some electrons in barium metal to eject them from the surface at high speed. To measure the maximum energy of the electrons, another plate above the barium surface is kept at a negative enough potential that the emitted electrons are slowed down and stopped, and return to the barium surface. See Fig. 17–46. If the plate voltage is -3.02 V (compared to the barium) when the fastest electrons are stopped, what was the speed of these electrons when they were emitted?

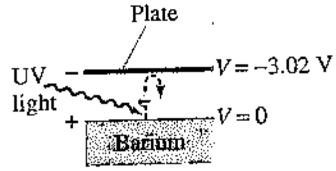

FIGURE 17–46 Problem 80.

81. A $+38\,\mu$C point charge is placed 36 cm from an identical $+38\,\mu$C charge. A $-1.5\,\mu$C charge is moved from point A to point B as shown in Fig. 17–47. What is the change in potential energy?

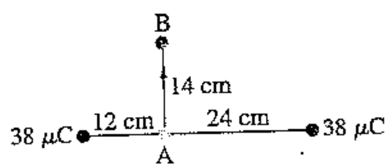

FIGURE 17–47 Problem 81.

82. Paper has a dielectric constant $K = 3.7$ and a dielectric strength of 15×10^6 V/m. Suppose that a typical sheet of paper has a thickness of 0.11 mm. You make a "homemade" capacitor by placing a sheet of 21 × 14 cm paper between two aluminum foil sheets (Fig. 17–48) of the same size. (*a*) What is the capacitance C of your device? (*b*) About how much charge could you store on your capacitor before it would break down?

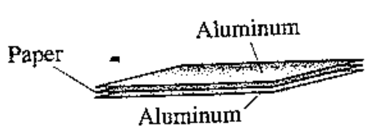

FIGURE 17–48 Problem 82.

83. A capacitor is made from two 1.1-cm-diameter coins separated by a 0.10-mm-thick piece of paper ($K = 3.7$). A 12-V battery is connected to the capacitor. How much charge is on each coin?

84. A $+3.5\,\mu$C charge is 23 cm to the right of a $-7.2\,\mu$C charge. At the midpoint between the two charges, (*a*) determine the potential and (*b*) the electric field.

85. A parallel-plate capacitor with plate area 3.0 cm^2 and air-gap separation 0.50 mm is connected to a 12-V battery, and fully charged. The battery is then disconnected. (*a*) What is the charge on the capacitor? (*b*) The plates are now pulled to a separation of 0.75 mm. What is the charge on the capacitor now? (*c*) What is the potential difference between the plates now? (*d*) How much work was required to pull the plates to their new separation?

86. A 2.1-μF capacitor is fully charged by a 6.0-V battery. The battery is then disconnected. The capacitor is not ideal and the charge slowly leaks out from the plates. The next day, the capacitor has lost half its stored energy. Calculate the amount of charge lost.

87. Two point charges are fixed 4.0 cm apart from each other. Their charges are $Q_1 = Q_2 = 6.5\,\mu$C, and their masses are $m_1 = 1.5$ mg and $m_2 = 2.5$ mg. (*a*) If Q_1 is released from rest, what will be its speed after a very long time? (*b*) If both charges are released from rest at the same time, what will be the speed of Q_1 after a very long time?

88. Two charges are placed as shown in Fig. 17–49 with $q_1 = 1.2\,\mu$C and $q_2 = -3.3\,\mu$C. Find the potential difference between points A and B.

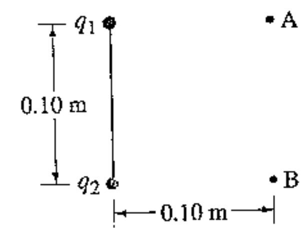

FIGURE 17–49 Problem 88.

89. If the electrons in a single raindrop, 3.5 mm in diameter, could be removed from the Earth (without removing the atomic nuclei), by how much would the potential of the Earth increase?

90. Thunderclouds may develop a voltage difference of about 5×10^7 V. Given that an electric field of 3×10^6 V/m is required to produce an electrical spark within a volume of air, estimate the length of a thundercloud lightning bolt. [Can you see why, when lightning strikes from a cloud to the ground, the bolt has to propagate as a sequence of steps?]

91. A manufacturer claims that a carpet will not generate more than 6.0 kV of static electricity. What magnitude of charge would have to be transferred between a carpet and a shoe for there to be a 6.0-kV potential difference between the shoe and the carpet? Approximate the area of the shoe and assume the shoe and carpet are large sheets of charge separated by a small distance $d = 1.0$ mm.

92. Compact "ultracapacitors" with capacitance values up to several thousand farads are now commercially available. One application for ultracapacitors is in providing power for electrical circuits when other sources (such as a battery) are turned off. To get an idea of how much charge can be stored in such a component, assume a 1200-F ultracapacitor is initially charged to 12.0 V by a battery and is then disconnected from the battery. If charge is then drawn off the plates of this capacitor at a rate of 1.0 mC/s, say, to power the backup memory of some electrical device, how long (in days) will it take for the potential difference across this capacitor to drop to 6.0 V?

93. An electron is accelerated horizontally from rest by a potential difference of 2200 V. It then passes between two horizontal plates 6.5 cm long and 1.3 cm apart that have a potential difference of 250 V (Fig. 17–50). At what angle θ will the electron be traveling after it passes between the plates?

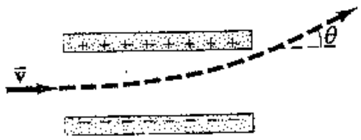

FIGURE 17–50 Problem 93.

94. In the **dynamic random access memory (DRAM)** of a computer, each memory cell contains a capacitor for charge storage. Each of these cells represents a single binary-bit value of "1" when its 35-fF capacitor ($1\ \text{fF} = 10^{-15}\ \text{F}$) is charged at 1.5 V, or "0" when uncharged at 0 V. (*a*) When fully charged, how many excess electrons are on a cell capacitor's negative plate? (*b*) After charge has been placed on a cell capacitor's plate, it slowly "leaks" off at a rate of about 0.30 fC/s. How long does it take for the potential difference across this capacitor to decrease by 2.0% from its fully charged value? (Because of this leakage effect, the charge on a DRAM capacitor is "refreshed" many times per second.) Note: A DRAM cell is shown in Fig. 21–29.

95. In the DRAM computer chip of Problem 94, suppose the two parallel plates of one cell's 35-fF capacitor are separated by a 2.0-nm-thick insulating material with dielectric constant $K = 25$. (*a*) Determine the area A (in μm^2) of the cell capacitor's plates. (*b*) If the plate area A accounts for half of the area of each cell, estimate how many megabytes of memory can be placed on a 3.0-cm^2 silicon wafer. (1 byte = 8 bits.)

96. A parallel-plate capacitor with plate area $A = 2.0\ \text{m}^2$ and plate separation $d = 3.0$ mm is connected to a 35-V battery (Fig. 17–51a). (*a*) Determine the charge on the capacitor, the electric field, the capacitance, and the energy stored in the capacitor. (*b*) With the capacitor still connected to the battery, a slab of plastic with dielectric strength $K = 3.2$ is placed between the plates of the capacitor, so that the gap is completely filled with the dielectric (Fig. 17–51b). What are the new values of charge, electric field, capacitance, and the energy stored in the capacitor?

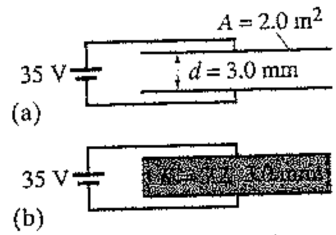

FIGURE 17–51 Problem 96.

Search and Learn

1. Make a list of rules for and properties of equipotential surfaces or lines. You should be able to find eight distinct rules in the text.

2. Figure 17–8 shows contour lines (elevations). Just for fun, assume they are equipotential lines on a flat 2-dimensional surface with the values shown being in volts. Estimate the magnitude and direction of the "electric field" (*a*) between Iceberg Lake and Cecile Lake and (*b*) at the Minaret Mine. Assume that up is $+y$, right is $+x$, and that Cecile Lake is about 1.0 km wide in the middle.

3. In lightning storms, the potential difference between the Earth and the bottom of thunderclouds may be 35,000,000 V. The bottoms of the thunderclouds are typically 1500 m above the Earth, and can have an area of 110 km^2. Modeling the Earth–cloud system as a huge capacitor, calculate (*a*) the capacitance of the Earth–cloud system, (*b*) the charge stored in the "capacitor," and (*c*) the energy stored in the "capacitor."

4. The potential energy stored in a capacitor (Section 17–9) can be written as either $CV^2/2$ or $Q^2/2C$. In the first case the energy is proportional to C; in the second case the energy is proportional to $1/C$. (*a*) Explain how both of these equations can be correct. (*b*) When might you use the first equation and when might you use the second equation? (*c*) If a paper dielectric is inserted into a parallel-plate capacitor that is attached to a battery (V does not change), by what factor will the energy stored in the capacitor change? (*d*) If a quartz dielectric is inserted into a charged parallel-plate capacitor that is isolated from any battery, by what factor will the energy stored in the capacitor change?

5. Suppose it takes 75 kW of power for your car to travel at a constant speed on the highway. (*a*) What is this in horsepower? (*b*) How much energy in joules would it take for your car to travel at highway speed for 5.0 hours? (*c*) Suppose this amount of energy is to be stored in the electric field of a parallel-plate capacitor (Section 17–9). If the voltage on the capacitor is to be 850 V, what is the required capacitance? (*d*) If this capacitor were to be made from activated carbon (Section 17–7), the voltage would be limited to no more than 10 V. In this case, how many grams of activated carbon would be required? (*e*) Is this practical?

6. Capacitors can be used as "electric charge counters." Consider an initially uncharged capacitor of capacitance C with its bottom plate grounded and its top plate connected to a source of electrons. (*a*) If N electrons flow onto the capacitor's top plate, show that the resulting potential difference V across the capacitor is directly proportional to N. (*b*) Assume the voltage-measuring device can accurately resolve voltage changes of about 1 mV. What value of C would be necessary to resolve the arrival of an individual electron? (*c*) Using modern semiconductor technology, a micron-size capacitor can be constructed with parallel conducting plates separated by an insulator of dielectric constant $K = 3$ and thickness $d = 100$ nm. What side length ℓ should the square plates have (in μm)?

ANSWERS TO EXERCISES

A: (*a*) -8.0×10^{-16} J; (*b*) 9.8×10^5 m/s.
B: (*c*).
C: 0.72 J.
D: (*c*).
E: A.
F: (*a*) 3 times greater; (*b*) 3 times greater.
G: 12 mF.